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RESEARCH OF HEAT GENERATION AND CONSUMPTION MODES IN COMBINED HEAT SUPPLY SYSTEMS USING ALTERNATIVE ENERGY SOURCES

Г. Лужанська, М. Галацан, М. Сергеєв, С. Грищенко, П. Кандєєв. **Дослідження режимів генерації та споживання теплоти у комбінованих системах теплопостачання з використанням альтернативних джерел енергії.** Альтернативна енергетика в теперішній час має всі технічні засоби, які дозволяють вважати її класичним доповненням до традиційних методів одержання енергії. Сучасні енерготехнології вимагають більш ефективного і надійного розв'язання задачі енергозабезпечення на основі інтегрованого використання різних видів відновлювальних джерел енергії, акумуляторів енергії різного типу, теплових насосів, комбінованих засобів термомодернізації будівель та дублерів енергії на альтернативному паливі. В сучасних системах теплопостачання із використанням альтернативних джерел енергії застосовують зазвичай не менше 2х джерел теплоти – відновлювальне джерело теплоти та традиційне джерело в якості резервного та пікового. Проаналізована робота газових, твердопаливних, пелетних та електричних котлів, сонячних колекторів, різних видів теплових насосів у системах теплопостачання будинків та споруд цивільного призначення. На якісну роботи системи теплопостачання впливають різноманітні схеми підключення споживачів до генераторів теплоти. Визначено особливості ефективної роботи системи комбінованого теплопостачання є узгодження різних гідравлічних режимів «генератор-споживач». На практиці для узгодження режимів роботи альтернативних системи теплопостачання із споживачами застосовують три підходи: регулювання потужності джерела теплоти, програмування режимів споживання теплоти, впровадження акумуляторів тепла. Важливим є з'ясування умов ефективного використання акумуляторів теплоти для переривчастого режиму опалення, що здатне забезпечити зменшення теплової потужності генератора теплоти, який працює в режимі надтопу. Досліджена робота пілотної установки інтегрованої система альтернативного постачання теплоти (ІСАПТ), проаналізовано отримані техніко-економічні показники для опалювального періоду для трьох різних видів генераторів теплоти: газовий котел, пелетний котел, тепловий насос. Експериментальне дослідження комбінованої системи теплопостачання для різних об'єктів теплозабезпечення дозволило встановити, що для будинків громадського призначення, раціональним шляхом підвищення їх ефективності є використання режимів переривчастого опалення, двоступеневої системи акумулювання, узгодження конструктивних і режимних параметрів основних контурів системи.
Ключові слова: комбінована система теплопостачання, котел, сонячний колектор, тепловий насос, акумулятор тепла

G. Luzhanska, M. Galatsan, M. Serheiev, S. Gryshchenko, P. Kandieiev. **Research of heat generation and consumption modes in combined heat supply systems using alternative energy sources.** Alternative energy currently has all the technical means that allow it to be considered a classic addition to traditional methods of energy production. Modern energy technologies require a more effective and reliable solution to the problem of energy supply based on the integrated use of various types of renewable energy sources, energy accumulators of various types, heat pumps, combined means of thermal modernization of buildings and alternative fuel energy backups. In modern heat supply systems using alternative energy sources, usually at least 2 heat sources are used - a renewable heat source and a traditional source as reserve and peak. The operation of gas, solid fuel, pellet and electric boilers, solar collectors, various types of heat pumps in the heat supply systems of buildings and civilian buildings is analyzed. The high-quality operation of the heat supply system is affected by various schemes of connecting consumers to heat generators. The specifics of the effective operation of the combined heat supply system are the coordination of various hydraulic "generator-consumer" modes. In practice, three approaches are used to coordinate the modes of operation of alternative heat supply systems with consumers: regulation of the power of the heat source, programming of heat consumption modes, introduction of heat accumulators. It is important to find out the conditions for the effective use of heat accumulators for intermittent heating mode, which can ensure a decrease in the thermal power of a heat generator operating in superheat mode. The operation of the pilot plant of the integrated system of alternative heat supply (ISAHS) was studied, the technical and economic indicators obtained for the heating period for three different types of heat generators: gas boiler, pellet boiler, heat pump were analyzed. An experimental study of the combined heat supply system for various heat supply facilities made it possible to establish that for public buildings, a rational way to increase their efficiency is the use of intermittent heating modes, a two-stage storage system, and coordination of structural and mode parameters of the main contours of the system.
Keywords: combined heat supply system, boiler, solar collector, heat pump, heat accumulator

Introduction

In connection with the acute shortage of fuel and energy resources in the world, issues related to the use of innovative technologies based on renewable energy sources in energy systems are urgent. Energy saving technologies using renewable energy sources in heat supply systems make it possible to fully use alternative resources, significantly reducing the consumption of fuel and energy resources [1 – 4].

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Alternative energy currently has all the technical means that allow it to be considered a classic addition to traditional methods of energy production. However, modern energy technologies require a more effective and reliable solution to the problem of energy supply based on the integrated use of various types of renewable energy sources (RES) (solar collectors, soil, wastewater, etc.), energy accumulators of various types, heat pumps, combined means of thermal modernization of buildings and alternative fuel energy backups.

In combined heat supply systems using alternative energy sources, two or more energy sources are used, one of which is traditional for power reserve and covering peak loads, and the others are renewable heat sources. The work of each of them is determined by internal needs and changes in climatic conditions [5, 6].

Analysis of literary data and statement of the problem

Combined heat supply systems (CHS) are most common in private houses, cottages and hotels.

The following heat sources are mainly used in CHS:

– gas, solid fuel and liquid fuel boilers;

– electric boilers;

– heat pumps;

– solar systems.

Gas and solid fuel boilers are the most widespread heat generators in Ukraine.

Recently, taking into account the crisis situation in the country's heat energy sector, the share of gas boilers is gradually decreasing, while the share of solid fuel boilers, on the contrary, is increasing. In many cases, the existing heat supply system based on gas boilers is supplemented with solid fuel boilers. In these systems, as a rule, the gas boiler becomes a backup source of heat. Gas boilers are used in centralized, decentralized and individual heat supply systems. In contrast to solid fuel boilers, equipped with an improved fuel management system, they have a low inertia in the system of automatic regulation of the gas fuel combustion process, and are characterized by a significant range of regulation of released heat [7]. Now gas boilers are widely used in gas boiler houses, especially on the roofs of buildings and structures. The possibility of using heat generators (no more than two boilers with a maximum capacity of up to 100 kW each) greatly simplifies the maintenance of such boiler houses [8, 9].

Utility gas boilers can be divided according to the following characteristics:

– individual boilers for apartments and small houses (up to 32 kW with the possibility of hot water preparation);

– single-circuit wall-mounted boilers up to 100 kW for private houses and heat generators;

– single-circuit wall-mounted boilers up to 200 kW for cascade systems in heating boiler rooms;

– boilers on the floor up to 1 MW for decentralized boiler houses;

– boilers on the floor of more than 1 MW for decentralized boiler houses.

In the classification of boilers, each of the specified types performs different functions, while it should be taken into account that there is a competition for technical solutions between the installation of boilers on the floor of large capacity and cascade systems. Implementation of boilers on the floor simplifies the automation system, in some cases reduces heat loss with flue gases and requires lower capital costs. Implementation of cascading systems of boiler operation enables a more compact location of power equipment in the boiler room, expands the range of regulation (modulation degree) from the minimum load of one boiler to the maximum load of all cascade boilers. As the experience of the practical use of the cascade scheme in the boiler room shows, there are cases of a decrease in the efficiency factor due to an increase in heat losses that occur if uncontrolled air flows through the boiler in the off state are not prevented. This can lead to an emergency situation - defrosting of the circulation circuit and, accordingly, its failure.

There are various schemes for connecting consumers to boilers.

The scheme with one circuit and one pump is usually used in individual boilers with a small number of heating devices. Regulation of the heat load is usually carried out according to the temperature of the return line, taking into account the temperature of the outside air. Equipping heating devices with thermostatic regulators leads to a change in the hydraulic regime of the system and fluctuations in the flow rate of the coolant through the boiler's heat exchanger. This circumstance affects the efficiency of boiler operation. Installation of a distribution collector can balance the hydraulic system of consumers (heating, ventilation, hot water supply). But the fluctuation of the load also leads to a variable hydraulic mode of operation of the system and a corresponding decrease in the efficiency of the boiler.

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The use of individual pumps for each consumer can improve the hydraulic operation of the entire system. However, the presence of such types of heating system devices as “warm floor” can cause an imbalance of the total flow of coolant by consumers and the flow of coolant in the boiler circuit, which negatively affects the efficiency of the heat generator. In the operation of the “consumer-boiler” system, problems of a hydraulic nature often arise, which can be solved by installing a hydraulic expansion valve (hydraulic arrow or buffer tank) [10]. At the same time, the heat source produces the necessary power while maintaining hydraulic stability, in turn, consumers receive the required amount of heat with defined temperature characteristics. The use of this equipment showed the best technical and economic results, there was a significant reduction in fuel consumption, and the number of emergency situations decreased [7]. Solid fuel boilers have recently been increasingly used in communal heating. Issues of switching central heating boiler rooms to solid fuel are under consideration. Private houses and small and medium-sized businesses also use solid fuel boilers more often.

According to the power, solid fuel boilers for the needs of communal heating can be divided into:

– individual boilers with a heat capacity of up to 50 kW;
– low-power boilers from 50 to 200 kW;
– boilers of medium power from 200 to 1 MW;
– boilers with a large capacity of more than 1 MW.

According to the fuel used, boilers are divided as follows:

– pellet boilers;
– briquette boilers;
– boilers for storage combustion (waste, straw, etc.);
– boilers for burning firewood;
– coal boilers;
– combined boilers.

Among private buildings and small and medium-sized businesses, combined boilers are the most common, where you can burn both pellets and other types of solid fuel.

Pellet boilers are distinguished by greater automation, less inertia and a greater range of power regulation. Also, in most cases, pellet boilers do not require the use of safety measures. However, these boilers require pellet storage bunkers, fuel warehouses with standardized microclimate parameters.

Unlike pellet boilers, briquette boilers require constant supervision, in many cases there is no automated fuel supply line. Also, quite often additional equipment is needed for safe work (installation of emergency coolers or heat accumulators). All these sources of heat require the installation of additional tanks to coordinate generator-consumer modes of operation.

Despite the fact that Ukraine has quite large opportunities for electricity production, the problem of equalizing electricity consumption throughout the day is urgent. Electric boilers are widely used in heating systems of residential buildings and commercial facilities. Including in rooms not equipped with a chimney, thanks to which they can be installed in apartments of apartment buildings. They are distinguished by their compactness, exceptional safety and ease of use. They do not require regular cleaning, loading and lighting of fuel, do not generate smoke and soot.

Electric boilers are the most rational from the point of view of heat supply modes of houses, which can be divided into:

– electrode boilers - need a certain concentration of salt for efficient operation, but an exaggeration of the concentration of salt in the coolant can cause the boiler to fail. Therefore, it is necessary to strictly observe the operating conditions, for which, when connecting the boiler to the heat supply system, a separate heat exchange device is installed;

– resistance boiler – unlike an electrode boiler, it is integrated directly into the heat supply circuit, and the required power is maintained by changing the resistance of the heating element.

It should be noted that in the summer, when there is only a need for hot water supply, it is necessary to coordinate the generation and consumption of heat by using heat accumulators, because frequent starts and stops of the boiler can lead to a decrease in the efficiency and resource of the heat generator.

In the heat supply systems of public buildings and buildings, air conditioning systems of the “chiler-fancoil” type are increasingly being used. In this case, the chiller is used as a heat pump. Also, in private houses, the use of a combined heat supply system with a heat pump as the main source of heat energy is of great interest.

It should be noted that the leading manufacturers provide the function of a heat pump in almost all modern air conditioning systems.

Heat pumps can be classified according to:

– by heat source (external air, soil, reservoirs, air of underground caves, life products (sewage, industrial waste, etc.);

– by technological system (cooling, hydronic).

The most common, for cost reasons, are local refrigerant heat pumps with heat extraction from outside air, so-called split air conditioning systems. The advantage of these systems is low cost, relatively high transformation ratio, ease of installation and maintenance. However, there are certain disadvantages - the use of these systems for heating the building is limited to heating and ventilation, but it is impossible to provide hot water and technological needs. In addition, for the heating system when using split systems of heat pumps, it is necessary, according to regulatory documentation [11 – 14], to use an additional heating system.

It should also be noted that split systems with wall-mounted indoor units are usually used, in which the sound pressure level exceeds permissible standards. Another disadvantage of such systems is the limited distance between the indoor and outdoor units.

More advanced freon systems are multi-zone systems (VRV, VRF) where one outdoor unit has several indoor units. The distance between the external and internal blocks reaches 100 m. It is advisable to equip such systems with heat recuperators for hot water supply needs and provide for regeneration in the off-season with the possibility of extracting heat from rooms that require cooling, with further transfer of heat to rooms that need heating. These systems can provide heating needs at outdoor temperatures down to -25°C.

A decrease in the transformation coefficient in such systems leads to an increase in electrical power or a decrease in thermal power [15]. Both the first and second circumstances are negative, because such systems require power backup at the expense of traditional heating systems.

More interesting from the point of view of combined heat supply systems is the “chiller-fancoil” hydronic system. Hydronic systems, unlike cold systems, do not need to be backed up by traditional heating devices.

Using, for example, the heat of the soil as a source of low-potential heat, allows you to stabilize the value of the transformation coefficient of the heat pump, but there are certain obstacles to the widespread use of such systems: it is known that heat from the soil can be extracted using horizontal or vertical pipes.

The use of horizontal pipes leads to an exaggerated area of land for their location (if this area may be enough for a private building, it is a problem for a multi-story building).

The use of vertical collectors, in addition to requiring coordination with state services, is more difficult to maintain the system and more expensive, respectively.

By design, the most common solar collectors are divided into:

– flat solar collectors;

– vacuum solar collectors.

Solar collectors are widely used in combined heat supply systems. SCs make it possible to reduce the share of consumption of natural fuels and electricity for the needs of hot water supply and technological needs (for example, heating water in swimming pools) [16]. Residual heat can be discharged into the heating system (underfloor heating). It is worth pointing out the dependence of the height of the building on the share of heat replacement. The most rational is the use of solar systems for low-rise buildings (no more than 4 floors).

The operation of the solar heat supply system is characterized by diurnal irregularity. As a result, in CHS, it is recommended to use heat accumulators for efficient operation of the system [17]. It should also be taken into account that solar systems differ in the annual unevenness of thermal productivity. This forces a careful approach to the calculation of the technical characteristics of the heliopolis, taking into account consumption needs and climatic factors. Thus, when using solar installations in CHS, in order to achieve the maximum effect of using solar radiation, it is necessary to pay attention to the annual accumulation of heat.

For example, in Sweden during the summer heat is stored in large underground reservoirs with the help of solar systems. Then, during the heating period, the battery is first discharged naturally, and then with the help of heat pumps.

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In Canada, there is a pilot project for heating a cottage town using solar systems, annual storage and heat pumps. Soil is used as an accumulating material.

The purpose of this work is to solve the problem of combined heat production using alternative energy sources and batteries, taking into account climatic factors.

To achieve this goal, it is necessary to solve the following problems:

– analysis of the current state of application of various energy sources in combined heat supply systems;

– research of different types of heat sources and combinations of their mutual application;

– determining the effectiveness of alternative heat sources in combined heat supply systems using batteries and taking into account internal and external factors.

Research materials and methods

The analysis of the state of the research problem showed that the use of renewable heat sources in existing combined heat supply systems reveal certain problems of coordinating heat production and consumption modes.

In practice, the following three approaches are used to coordinate the operating modes of alternative heat supply systems with consumers: regulation of the power of the heat source, programming of heat consumption modes, introduction of heat accumulators. The latter is extremely important when using solar collectors in combined heat supply systems. The uneven schedule of heat production and consumption in solar systems indicates the need to coordinate modes by installing a buffer capacity, namely a heat accumulator.

It is important to find out the conditions for the effective use of heat accumulators for intermittent heating mode, which can ensure a decrease in the thermal power of a heat generator operating in superheat mode.

In addition, it is necessary to justify the choice of rational modes of operation of combined heat supply systems with electric boilers that use the night tariff for electricity to accumulate heat.

The above features indicate the need for a rational approach to choosing the volume of the thermal accumulator of heat supply systems, which depends on the outside air temperature, for example, for the city of Odesa:

– when choosing the maximum volume of the accumulator (for the minimum calculated temperature of the outside air according to parameters B: –18 °C, a cold five-day period) it is possible to fully ensure the needs for heat during the night period, but the capital costs will be unjustified, because in the period when the temperature of the outside air above –18 °C, excessive heat losses of the battery (negative effect) will nullify the useful;

– when choosing the volume of the accumulator (for the calculated temperature of the outside air according to parameters A: –6 °C, cold thirty days), although the heat needs can be provided not completely during the night period, but the capital costs are significantly reduced. When the outside air temperature is below –6 °C, the power deficit can be compensated for by daytime electrical load dips and reduction of heat losses by the battery. In addition, an additional beneficial effect is that the maximum electrical power during the battery charging period is reduced.

When carrying out complex solutions for thermal modernization of the building and installation of heat pumps with heat accumulation based on a phase transition, taking into account the schedule of energy consumption for household needs, it is possible to provide heat to consumers without significantly increasing the electric power.

Another feature of coordinating the operation modes of heat supply systems with consumers is the dependence of the operation of the heat source on natural conditions. Thus, gas, electric and solid fuel boilers are practically independent of natural conditions. The power (or required electrical power) of heat pumps with a heat source - outside air depends on the temperature outside. The operation of solar systems depends on both the time of year and the hour of the day.

Among consumers, there is also unevenness of work throughout the year and day. Thus, the hot water supply system is characterized by an uneven heat load throughout the day with characteristic peaks in the morning and evening. If this load is imposed on the schedule of daily heat consumption, the need to increase the maximum power of the heat source becomes obvious. Accumulator water heaters are usually installed to prevent an increase in the calculated capacity of heat sources. This circumstance equalizes the heat load for the needs of hot water supply during the day.

The heating system changes its load throughout the year. At the same time, during the day, significant fluctuations are observed only when using the two-period mode of heating the premises. To coordinate the operating modes, it is necessary to install a hydraulic distributor or a buffer tank. It should also be noted that if the "underfloor heating" system has a predominant contribution to the heating system, then there is a problem of the inability of the gas condensing boiler to enter the condensing mode, and the heat pump to provide the necessary temperature in the supply line of the "underfloor heating" system (heat exchanger of the boiler and heat pump unable to pass the necessary flow of coolant with the required temperature). In such cases, at least two boilers should be installed. The heat supply of the ventilation system depends on the temperature of the outside air and the mode of operation of the building, so fluctuations in the heat load are possible both during the year and during the day. Coordinating the operation of the ventilation systems and the heat source is possible due to the modulation of the heat supply system.

Taking into account the above, in order to coordinate the operation of the combined heat supply system with the use of renewable energy sources and heat consumers, it is necessary to install heat accumulators. The capacity of heat accumulators is determined by the peak difference of heat consumption/output.

In addition, an important issue of the efficient operation of the heat supply system is the coordination of hydraulic modes "generator-consumer". Thus, the operation of the condensing boiler in the effective mode occurs at a temperature in the supply line not higher than +55 °C, while the temperature difference between the supply and return lines is not less than 15 °C (according to the boiler's passport data, it is usually 20 °C). This temperature in the supply line is most justified for the "warm floor" system.

However, the temperature regime of the "warm floor" system does not exceed 5 °C, therefore, with large percentages of heat supply to the "warm floor" due to different hydraulic modes (a four-fold difference in costs), the temperature of the boiler exceeds the condensation mode and the efficiency of the system is significantly reduced.

Unlike boilers, a heat pump (single-stage) has a temperature in the supply line of no more than +55 °C, but the difference between the supply and return lines usually does not exceed 10 °C (and may be less). In this case, not only the temperature regimes in the "generator-consumer" system, but also the hydraulic regimes are coordinated.

Research results

The pilot installation of ISAHS was installed in the educational building of the Odessa Polytechnic National University.

During the study of the ISAHS pilot plant, technical and economic indicators were calculated for the 2016-2017 heating period for three heat generators: a gas boiler, a pellet boiler, and a heat pump (Figure). The following energy tariffs were used in the calculations:

– natural gas UAH 11.7/m^3 (including transportation);

– pellets 3.2 hryvnias/kg (from wood with a calorific value of 12 MJ/kg);

– electricity 2.4 hryvnias/kWh.

Options were calculated for three modes:

1. Basic (constant heat supply);
2. Application of ISAHS;
3. Application of ISAHS with the use of combined insulation and without a duty cycle.

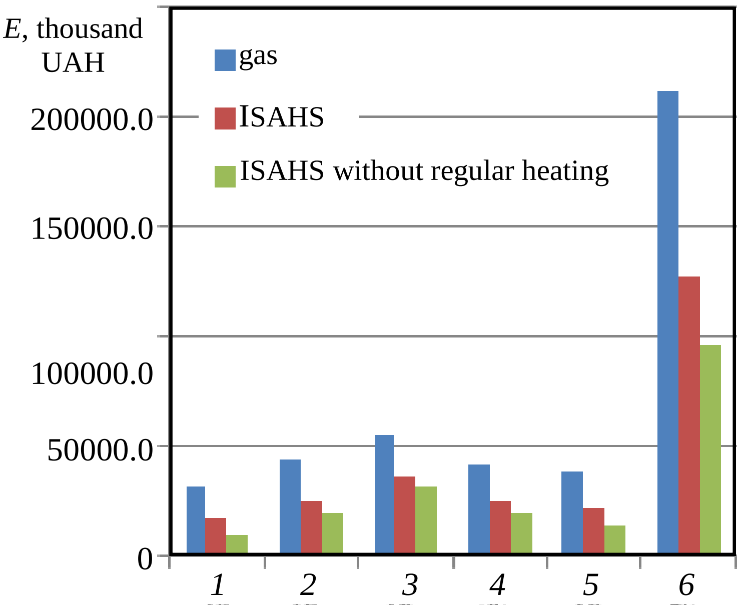

Figure. Operating costs of ISAHS during the 2022 – 2023 heating period: *1* – November; *2* – December; *3* – January; *4* – February; *5* – March; *6* – Totally

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Analysis of the graph (Figure) shows significant savings from the use of ISAHS (about 40%), as well as additional savings (10%) from the use of combined thermal insulation and the rejection of the duty mode.

At the same time, the capital expenditure ratio for the main equipment is:

– with the estimated capacity of heat generators 100% – 520 thousand UAH.

– taking into account the accumulation parameter of substitution of UAH 300,000.

It should be noted that the duration of operation at a workload of less than 50% is 85% (outside air temperature –5 °C and higher), while the duration of operation at a workload of 90…100% is less than 4%.

Modes of use of each of the heat sources in ISAHS depend on the technical characteristics of the equipment.

Thus, it is advisable to use heat pumps with heat extraction from outside air at temperatures not lower than –5 °C [14].

When using solar collectors, the question arises as to what proportion of heat replacement should be focused on. The conducted studies show that the most effective is the use of solar systems for the preparation of hot water for the needs of water supply and water heating in hotel swimming pools, if available.

One of the problems of using heat generators is their joint operation:

The combination “gas boiler - solid fuel boiler”:

The joint use of gas and solid fuel boilers is a technical and economic problem, because it is necessary to justify what is more appropriate – the use of a solid fuel boiler on firewood, pellets, coal, etc. with a relatively low cost of heat, but a small adjustment range, or a gas boiler, which is more simple maintenance and has a wider power adjustment range than a solid fuel boiler.

This was especially relevant when pricing gaseous fuel, according to the consumed volume according to the tariff grids that were used until 2015. At the same time, the solid fuel boiler was used as an emergency boiler.

The combination “heat pump - solar collectors” (HP with SC):

The use of heat pumps compatible with the circuit of the solar collector as part of the combined heat supply system leads to an increase in the efficiency of the heat pump at the same time as the area of the solar collector modules is reduced.

But, it should be noted that, in this case (HP with SC), it is also necessary to solve the technical and economic problem, which consists in the fact that it is necessary to find out which solution is more rational:

– heat water using a heat pump to the required temperature (55 °C), losing its efficiency;

– to heat water to a lower temperature (45 °C), using a more efficient operation of the heat pump installation, with the possibility of further heating in the modules of solar collectors to the required temperature of 55 °C, with the expenditure of additional capital funds for solar collectors.

Combination “gas boiler - heat pump” (GB with HP):

The advisability of using a gas boiler or a solid fuel boiler in combination with a heat pump requires a special approach to the feasibility study, because the following factors must be taken into account:

– the influence of the type of heat pump (air-air, water-water, air-water, water-air) on the volume of capital costs. Despite the fact that the lowest capital costs are inherent in the air-to-air heat pump, it cannot be integrated into a combined alternative heat supply system. On the contrary, a water-to-water heat pump integrates well into a combined system, has high efficiency, but is characterized by the highest capital costs;

– strict dependence of the heat pump power on the ambient temperature, namely, a decrease in the ambient temperature has an extremely negative effect on the thermal performance of the heat pump;

– a significant effect of a decrease in the ambient temperature on the increase in the temperature of the coolant in the heating system, namely, at low temperatures of the outside air (less than minus 5 °C), it is impossible to ensure the required temperature of the working fluid in the circuit of the heat pump condenser and, accordingly, the required temperature of the coolant (not lower than 55 °C) in the heating system;

– the effective use of the heat pump corresponds to the condition COP ≥ 2.5, because in the other case (low outside air temperature) the use of the heat pump becomes impractical due to the comparability of the cost of heat generation of the heat pump and traditional sources.

Conclusions

The analysis of the global experience of using CHS for various heat supply facilities made it possible to establish that for public buildings, a rational way to increase their efficiency is the use of intermittent heating modes, a two-stage storage system, and coordination of structural and mode parameters of the main circuits of the system (heat generator and consumers). For this purpose, theoretical and experimental studies (ISAHS) were carried out, namely, for public buildings, the nature of the influence of various factors on the system's operating modes, its energy and economic efficiency, and the technical and economic advantages of such a solution were determined.

Two sources of heat play a predominant role in the operation of the ISAHS with the corresponding share of the contribution to the heat productivity (heat pump 30% + pellet boiler 50%) or (gas boiler 50% + pellet boiler 50%), and the contribution of solar collectors during the heating period can be neglected. The share of the contribution to the heat productivity of pellet and gas boilers must be chosen based on the considerations that the capacity of each of the heat sources is 50% of the maximum required. The total power of pairs of heat sources involved in the ISAHS (heat pump + pellet boiler or gas boiler + pellet boiler) is able to provide the necessary heat to the educational building of the Odessa Polytechnic National University, where the pilot installation of the ISAHS is installed. Therefore, there is no need to use each pair of specified sources with maximum power, which allows you to significantly reduce capital investment in the combined heat supply system. The thermal efficiency of the heat pump is calculated on the compensation of heat losses at the temperature of the outside air $t_{outside} \geq$ minus 5 °C. A pellet boiler (energy doubler) is used to ensure the excess heat needs of the ISAHS when the superheat mode is forced, and the total number of solar collector modules is calculated based on the needs of hot water supply and the roof area of the educational building.

Література

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